International Journal of Engineering Applied Sciences and Technology, 2018
Vol. 3, Issue 5, ISSN No. 2455-2143, Pages 18-32

EXPERIMENTAL STUDY ON TWO-PHASE FLOW PRESSURE DROP USING FERROFLUID (Fe_3O_4) AND MAGNETIC FIELD IN SMALL DIAMETER TUBE BENDS

G.E. Chaudhari
Mechanical Engineering Department,
Maharashtra Institute of Technology, Aurangabad,
(Maharashtra), India

S. B. Charthankar
Mechanical Engineering Department,
Maharashtra Institute of Technology, Aurangabad,
(Maharashtra), India

B. G. Toksha
Mechanical Engineering Department
Maharashtra Institute of Technology, Aurangabad,
(Maharashtra), India

A.T. Autee
Mechanical Engineering Department,
Maharashtra Institute of Technology, Aurangabad,
(Maharashtra), India

Abstract— **Measurement of two-phase flow pressure drop and enhancement of heat transfer rate in presence of magnetic field using water-based ferrofluid (Fe3O4)nanoparticles and the air are studied in present work. Two-phase flow pressure drop prediction across curved bend tubes is an important parameter for enhancement of heat transfer rate in a heat exchanger. Test sections of copper tube of diameter range 8.0-12.0 mm used in this study. Comparative study of the pressure drop of the present experimental data and existing correlation has been carried out and it is found that most of these correlations are unable to predict present experimental data. It was observed that pressure drop increases with an increase in mass flow rates, ferrofluid concentration, and intensity of the magnetic field. This comparative study shows the good agreement with the present data.**

Keywords: **Bend tubes, Pressure drop, Air-nanofluid, Magnetic flux.**

I. INTRODUCTION

In recent year, fluid containing a deferment of nanometer-sized particles (nanofluid) is an active area of research due to their enhancement of thermal property over the base fluid. Bends are encountered in many industries equipment such as heat exchanger, transport piping etc.

Rana et al. (2010) faced several problems. the sedimentation, erosion of the compound by abrasive action, clogging in a small passage and increased pressure drop of the flow channel due to the large size of the particles during their study. Commonly nanoparticles below 100nm in diameter have relative large surface area that increases the stability and reduce the sedimentation of nanoparticles in nanofluid. The evaluation of the pressure loss in the fluid dynamic subcritical single phase as well as in two-phase flow are necessary. Basically, pressure loss is higher in a straight pipe with an equal cross flow section and mean length due to additionally established losses, but in bend, curvature causes centrifugal forces in a direction from momentum centre of curvature to the core moves outward and in the region near the wall inward. The secondary flow is superimposed to the mainstream along to the imposing axis, therefore the total pressure reaches to the streamlines in helical shape. This effect of the curvature for single-phase flow on the structure of flow was reviewed by Ito et al .(1987).

Two-phase pressure drops studied in convention channel using three well-known correlations by Lockhart & Martinelli, Chisholm & Friedel. The Lockhart& Martinelli's correlation was based on adiabatic flow of air and benzene, kerosene, water and various oil passing through 1.5-26 mm pipe and the pressure drop were correlated based on whether the individual liquid and gas were in the laminar and turbulent flow. Pierre et al., developed two-phase pressure drop correlation in return bend based on experiment includes the effect of fabrication and turning. Chisholm et al. (1987) and Pailwad et al. (1991) also developed correlation of two-phase pressure drop in return bend. Domanski et al. (2006) developed a new correlation fotwo-phase flow pressure drops in 180^0 return bend which consists of two-phase pressure drop for straight tube and multiplier that account for the bend curvature. Padilla et al. (1991) have studied 325 pressure-drop points' database that includes 3 different fluids (R-12, R-134a & R-410a) to propose correlation that includes only two empirical constants and exhibits the correct physical limits.

Spedding et al. (1982) reported pressure drop data for two-phase air-water flow through vertical to horizontal 90^0 elbow bend set in 0.026m. It was observed that a general increase in fluid rates that tapered off at high fluid rates and exhibited a negative pressure region at a low rate. The later was attributed to the flow being smoothly accommodated by the bend when it passed from slug flow in the riser to smooth stratified flow in the outlet tangent.

Silva et al.(2010) investigated two-phase pressure drop in elbow bend by comparing their experimental result with homogeneous model. Chisholm et al.(1983), Sookprasong et al.(1980), Kuhn Morris et al.(1997), Pailwada et al.(1992), Domanski et al.(2006), Autee and Giri et al.(2016), have developed correlations based on two-phase multiplier method. It is observed from the open literature that predicated value of pressure drop by this leading method may be differential by large.

The study of effects of magnetic field on two-phase flow pressure drop at fluid flow through curved tubes of different angle ranging from 45^0, 90^0, 180^0 in different orientation are widely employed in a heat exchanger and flow transmitting device. Venkatesh et al., (2010) studied two-phase flow pattern and pressure drop experimentally using air-water mixtures. The tube diameter used ranges from 0.6mm to 3.4mm. They compared experimental data with existing correlations.

The basic objective of the present work is to study experimentally and analytically, the characterization of two-phase pressure drop across the different bend angle of the range 45^0-180^0 in a horizontal orientation. The comparative study represents two-phase pressure drop using available correlation to access their predictive capabilities in the present range of the experimental parameter.

II. SYNTHESIS OF NANOFLUID

The nanoparticles and the distilled water are mixed directly. In general, there are three effective methods for the preparation of suspension: - 1. Changing the pH value of suspension. 2. Using surface activators and dispersants. 3. Using ultrasonic vibration. The use of these three techniques depends upon the application of nanofluid.

The Fe_3O_4 nanofluid is made by co-precipitation technique. The synthesis of Fe_3O_4nanoparticlesbased in the mixture of Ferrite Nitrate and surfactant Citric acid is used, which is to be mixed in the proportion of 40.4 gram of Ferrite Nitrate and 63.03 gram of Citric acid. The mixture is to be placed in the Borosil beaker of a capacity of 1 liter and this mixture is then dissolved in distilled water used up to 100 ml. The hotplate with stirrer is used to stir the mixture into proportion and the beaker is to be placed on that hot plate. The temperature of the hot plate is to be set up to 200^0c. A magnetic needle is to be used as a stirrer for proper stirring of the mixture is to be set at 1000 rpm for 6 hours. After some time 20 ml ammonium solution is to be added into the mixture and check the ph level of the solution up to 6 scales. So after 5 to 6 hours, the black mesh-like nanoparticles are prepared. The prepared nanoparticles are in black powder forms which are precipitated at wet condition. So, to make the nanoparticles dry and brown in colour, the black powder of nanoparticles is placed in the silica crucible of capacity 25 ml which is kept into the hot wall furnace at temperature 550^0c for a period of 6 hours. Finally, the brown colour nanoparticles are ready. The furnace heating removes the surfactant and moisture from the powder mixture.

The Fe_3O_4 nanoparticles are mixed in base fluid i.e. water to prepare Fe_3O_4 nanofluid. The volume of concentration is evaluating from the following

$$\% \text{ volume concentration} = \frac{\text{volume of nanoparticl}}{\text{e volume of nanoparticle + volume of water}} * 100$$

$$\emptyset \quad = \frac{\left({}^{m}/_{\rho}\right)_{\text{nanopartical}}}{\left({}^{m}/_{\rho}\right)_{\text{nanopartical}} + \left({}^{m}/_{\rho}\right)_{\text{water}}} * 100 \quad (1)$$

The nanofluid of different concentration 0.02 and 0.04 volume concentration is prepared. The prepared nanoparticles are to be mixed in equal proportion with water in the beaker and then this mixture is stirred with a rotating stirrer at 500 rpm for the period of 1 hour. Due to the use of the same method different concentration of nanofluid are prepared. The density of nanofluid is calculated by the following equation:

$$\rho_{\text{nf}} = (1-\phi)\rho_{\text{bf}} + \phi\rho_{\text{p}} \qquad (2)$$

III. EXPERIMENTAL SET UP

The experimental set up was designed and fabricated to conduct adiabatic air-nanofluid two-phase flow experiment in small diameter test sections and small diameter tube bends using a magnetic field. This experimental set-up consists of air and nanofluid circuit as shown in figure 1. The arrangement was made for mounting the test sections at a different orientation. There are two different plywood sections manufactured for less compliance. On first section mixing chamber, bypass valve is mounted and on another section the test section and data acquisition system is mounted.

Nanofluid from the nanofluid tank is pumped to the test section by a centrifugal pump. Nanofluid flow is controlled by the bypass valve. Similarly, the air flow rate is regulated through a set of hand shut off valve. Air and nanofluid are mixed in mixing chamber and measured by the Rotameter, connected in the series with air and nanofluid respectively. The test section is connected to the mixing chamber. Air-nanofluid mixture coming out from the test is collected in the nanofluid tank. In the tank air and nanofluid get separated and the nanofluid is re-circulated. Differential pressure transducer measures pressure at an inlet of the test section and across the bend. Data acquisition system records pressure drop data. In the test section, three angles 45^0 , 90^0 ,180^0 are applied with equally specific distance magnetic field. The different copper tubes with diameter 8.0,10.0 ,12.0 mm are used during the investigation.

Nanofluid and air flow rates are varied within the range from 2.5 to 3.5 LPM and 4.0 to 20 LPM respectively. The measuring range of this differential pressure transducer is between 0-1 bar. The pressure transducer of range 0-2.5 bar is used for measurement of the inlet static pressure. The following flow parameters are measured: flow rates of air and water, pressure drop and temperature recorded by a data acquisition system in the test section. Two Rotameters are used in this experiment to measure the mass flow rate. One is used for water flow line having a range 3-30 LPM while the other is used for airflow line having a range 10-100 LPM. A pressure gauge is located just before the inlet to the mixing chamber. This is used to measure the static pressure of air for calculation of density.

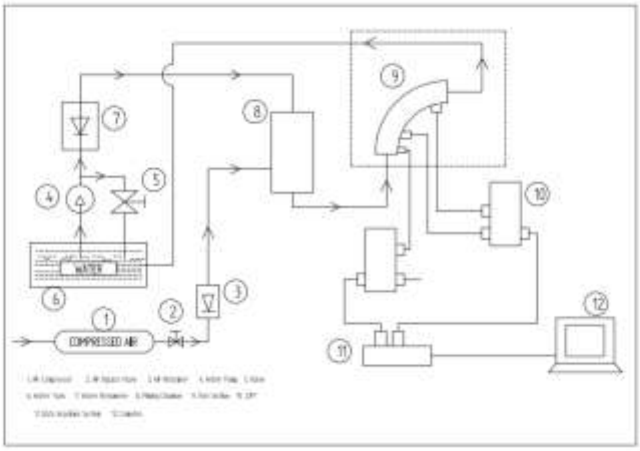


Fig 1. Schematic diagram of Experimental set up

The external magnetic field is generated by winding 200 numbers of turns of a small insulated copper wire on the GI pipes of 100 mm length and 20 mm outer diameter. A 12-volt DC power supply of transformer is then passed through this copper wire produces up to 400 Gauss constant magnetic field. Care was taken during copper tube insertion into an iron pipe and during bending operation so that the diameter of the tube remains constant throughout the test section.

IV. RESULT AND DISCUSSION

A. Experimental Validation

Single-phase pressure drop tests are conducted to validate experimental set-up and instrumentation. Experiments were conducted with 8.0 mm internal diameter and 300 mm length test section. Water is used as working fluid. The experimental pressure drop for water flow was recorded. Figure 2 shows the comparison of the experimental friction factor f with Blasius correlation predicted values. It is observed that experimental values are in good agreement with Blasius correlation ($\mathrm{f} = 0.079/\mathrm{Re}^{0.25}$) prediction. The error associated with the pressure drop measurements proves to be quite reasonable ±10%. The pressure drop data for different water flow rates are recorded and this is used to calculate the friction factor by applying the Darcy equation for the smooth pipe as:

$$\mathrm{f}_{\mathrm{exp}} = \frac{\Delta\mathrm{PD}}{2\mathrm{L}\rho\mathrm{v}^2} \qquad (3)$$

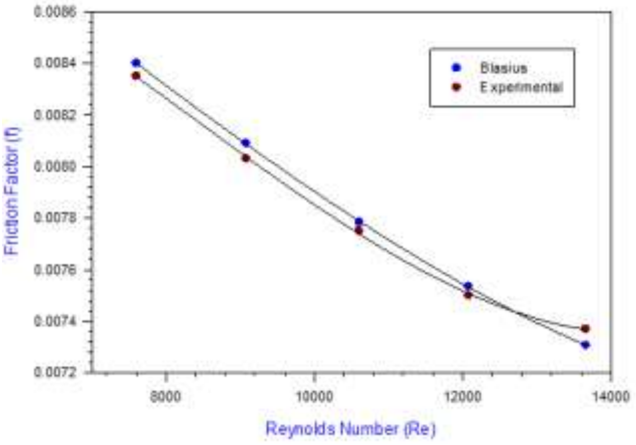


Fig 2.Comparison of experimental single-phase friction factor with Blasius correlation.

B. Comparisons of the Experimental Data with Existing Correlation

The experimentally measured two-phase pressure drop has been compared with the existing correlation. Two-phase pressure drop data has been comparing with existing correlation.

The correlations considered for comparison are Chisholm et al.(1983), Domanski et al.(2006), Silva et al.(2010), Kuhn et al.(1997), Sookprasong et al.(1980), Giri et al.(2016) These correlations are well accepted and generally used for calculation of two-phase pressure drop of bend tube sections. Figure 3 to 8 represent the comparison of frictional pressure drop calculated by the evaluated correlations with the experimental data. The abscissa denotes experimental pressure drop, while the coordinate indicates the predicted one. The error band of ±50% is shown by solid lines in these figures. The measured pressure drop for constant water flow rate and different bend are presented in Figure 3to 8 relative to a tube of 8, 10, 12mm respectively.

Figure 3 a-i shows the comparison of experimental frictional pressure drop data with the predictions of the Chisholm et al. (1983) flow model. This correlation over predicts for 12.0 mm diameter tube frictional pressure drop data, 0 % data points are within the ±50% error band for air-water mixture with 324.6% mean error. When nanofluid was used then friction pressure drop was found to be decreasing as compared with the air and water test .It was observed that as the bend angle increases, the pressure drop point increases.

Figure 4 a-i shows the comparison of experimental frictional pressure drop data with the Domanski et al.(2006) correlation. The predicted friction pressure drop data point decreases when diameter and tube angle increases within the ±50% band. When the correlation is compared with the air and water at one side and nanofluid and air at other side, resulting from this the friction pressure drop data point is within the ±50% band is slightly higher than that for air and water as compared with air and nanofluid. For diameter 8 mm tube with angle 45^0 Air and nanofluid with 0.04 concentration tube friction pressure drop point is 65% with the mean relative error of 38.78%. And when the same condition is applied with the magnetic field friction pressure drop point is 75 % and means relative error is 30.75%.

Figure 5 a-i shows the comparison with the Kuhn et al .(1997)correlation developed in 1997. This correlation predicts most of the friction pressure drop data point within ±50% error band. For diameter, 8 mm with angle 45^0 air and water tube friction pressure drop data point is 100% with a 14.94% mean error.

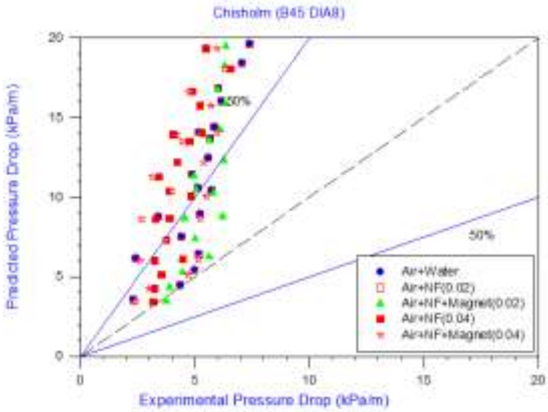
Figure 6 a-i has shown Giri et al.(2016) correlation data compared with the experimental data. Giri et al. (2016) has developed new correlation from the Domanski et al. (2006) correlation. It is observed that the friction factor increases as the bend and tube diameter increases. The friction pressure drop for 8mm diameter with angle 180^0 is 40% with relative mean error 50.63% with air and water mixture, when same case applied only by replacing water with nanofluid of 0.02 concentration then friction data point was found to be 65 % with a relative mean error of 43.70%. And when the magnetic field was applied, the same data point shows the same result with slight increase. For 10 mm diameter tube with angle 180^0 air and nanofluid 0.02 tube friction pressure drop point is 70% with the mean relative error of 48.88%. When the same condition was applied with the magnetic field friction pressure drop point is 75 % and the mean relative error is 47.81%. For 8 mm diameter tube with angle 90^0 air and nanofluid 0.04 tube friction pressure drop point is 45% with the mean relative error of 46.77%. And when the same condition was applied with magnetic field friction pressure drop point is 50 % and mean relative error is 45.75%.

Figure 7 a-i has shown the Silva et al.(2010) flow model for different bend and tube diameter. This correlation over predicts tube friction pressure drop data point only mean relative error is varied.

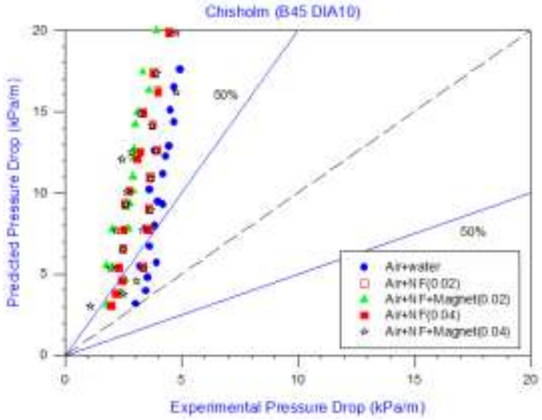
Figure 8 a-i has shows Sookprasong et al. (1980) correlation compared with experimental data. It is observed that for air and nanofluid in 8 mm diameter tube the friction factor data point is larger than the 12mm diameter and is within ±50% range. When the magnetic field was applied on the test section then the friction factor data points were slightly increased. For 8 mm diameter tube with angle 45^0 Air and nanofluid with 0.02 concentration tube friction pressure drop point is 40% with a mean relative error of 65.38%. When the magnetic field was applied on the same condition friction pressure drop point is observed to be 55% and the mean relative error is to be 62.14%.The highest friction pressure drop data point within ±50% band is found to be in 8mm diameter with angle 90^0 is 70% with relative mean error 42.21%.

From an overall study of the experimental results, it is observed that increase in flow rate of two-phase flow results in increased pressure drop. There may be also mean absolute errors due to the presence of some uncertainties like the density of fluid, viscosity, surface tension, test section dimensions, etc. This study also shows that when nanofluid is used as compared to the air-water mixture, the pressure drop is slightly decreased and increased as the concentration of fluid increases. As the diameter of the tube decreases then the pressure drops increases. Finally, due to the use of magnetic field as compared to the air-nanofluid mixture, the pressure drop increases slightly.

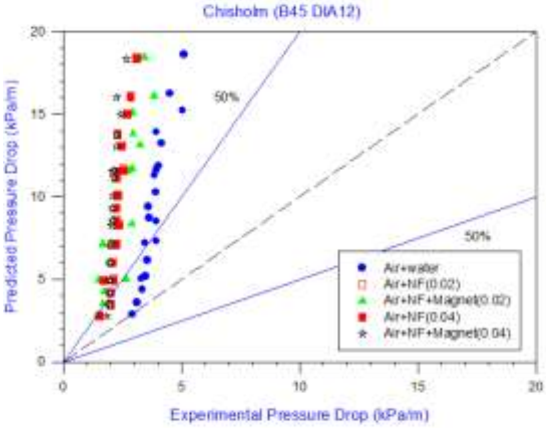
a)


Chisholm (B45 DIA8)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
● Air+Water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
☆ Air+NF+Magnet(0.04)

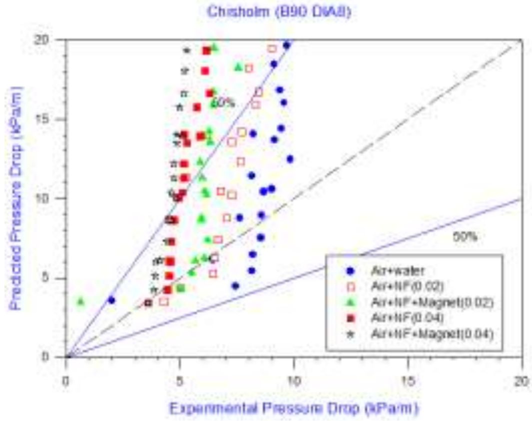
b)


Chisholm (B45 DIA10)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
● Air+water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
☆ Air+NF+Magnet(0.04)

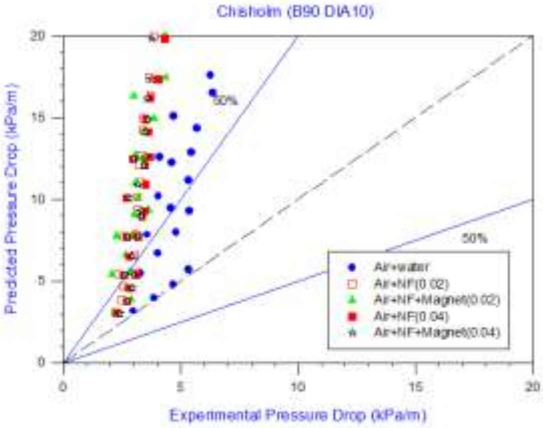
c)


Chisholm (B45 DIA12)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
● Air+water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
☆ Air+NF+Magnet(0.04)

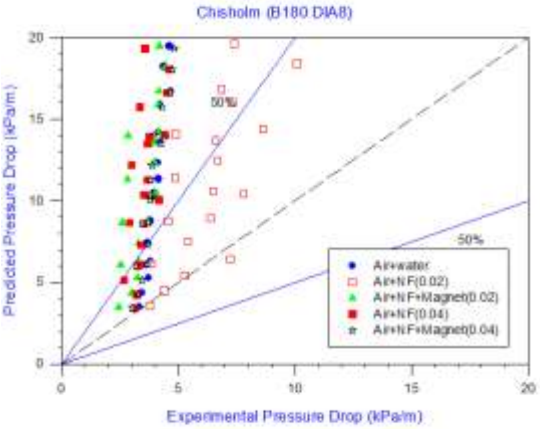
d)


Chisholm (B90 DIA8)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
● Air+water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
☆ Air+NF+Magnet(0.04)

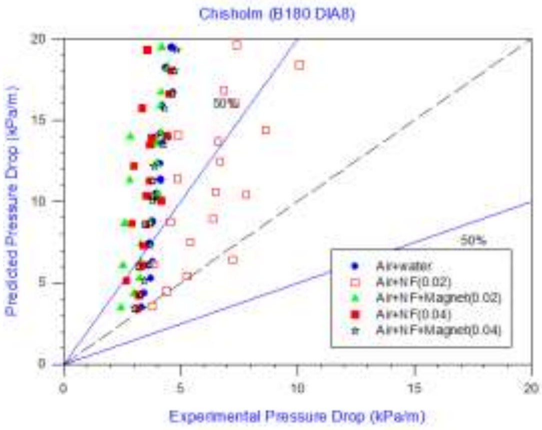
e)


Chisholm (B90 DIA10)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
● Air+water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
☆ Air+NF+Magnet(0.04)

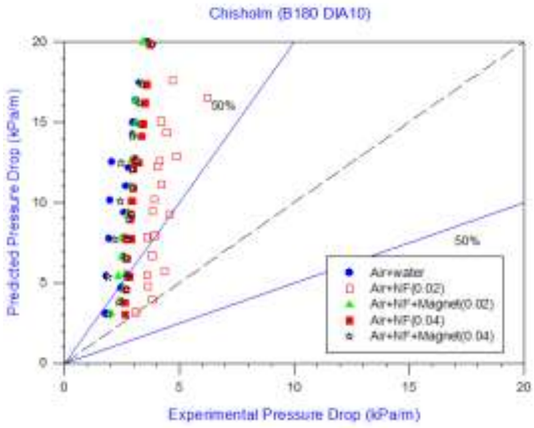
f)


Chisholm (B180 DIA8)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
● Air+water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
☆ Air+NF+Magnet(0.04)

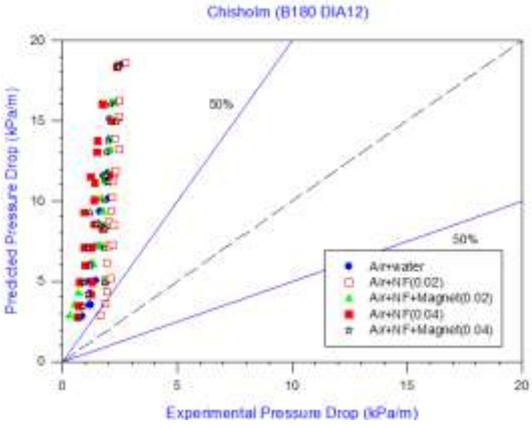
g)



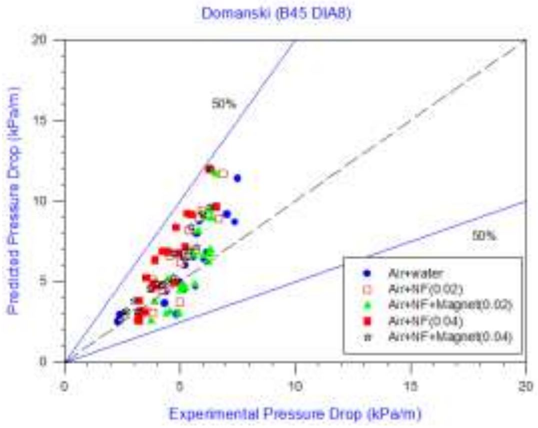
h)



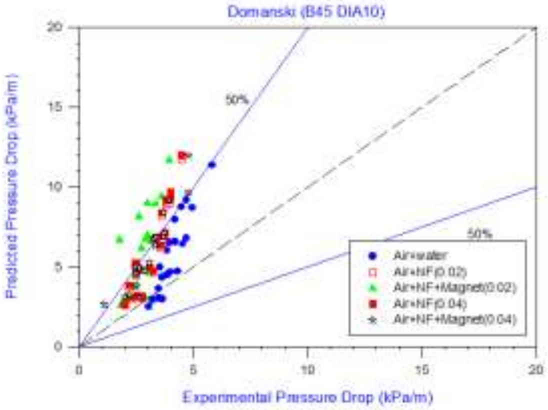
i)



a)



b)



c)

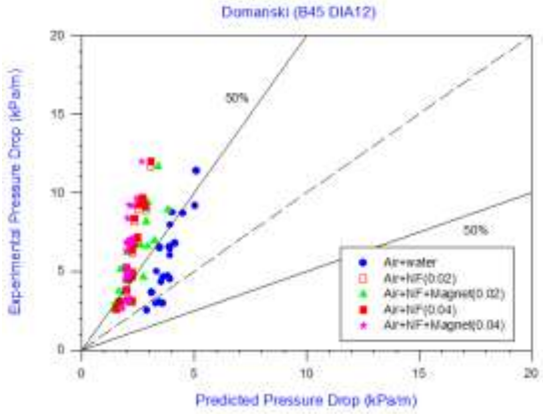
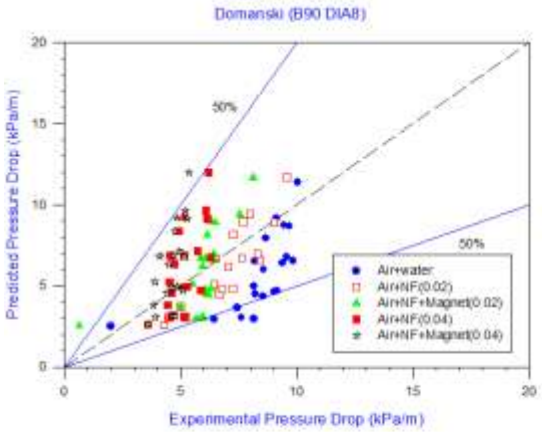
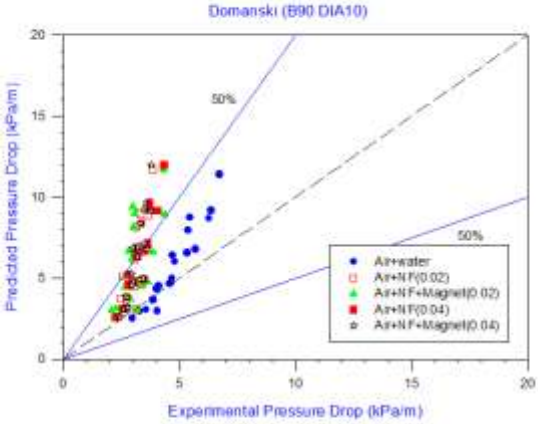


Fig.3 Comparison of various existing correlations with experimental data

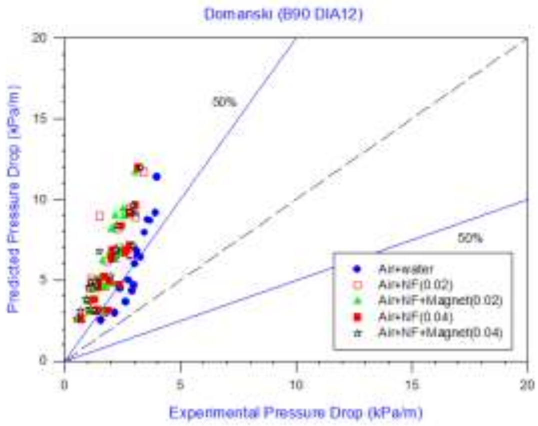
d)



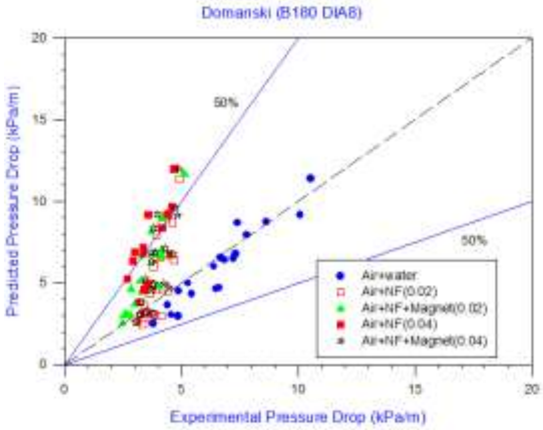
e)



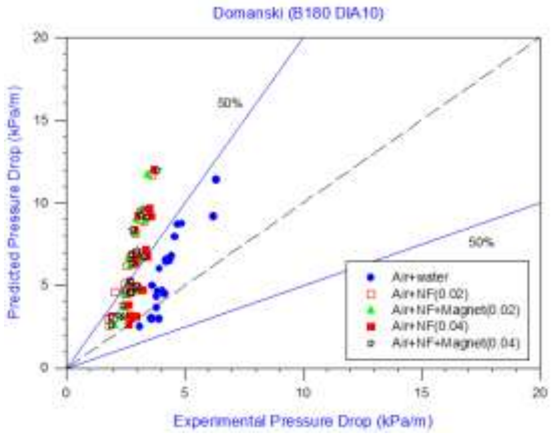
f)



g)



h)



i)

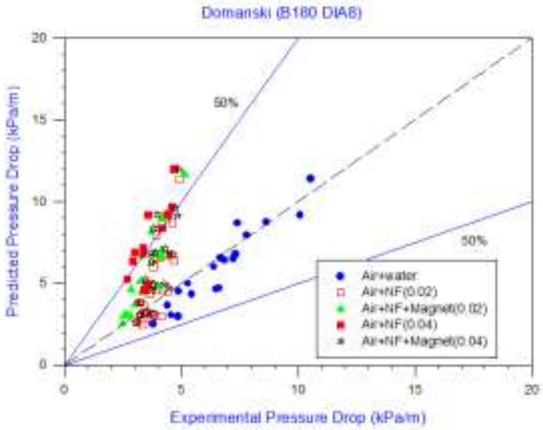
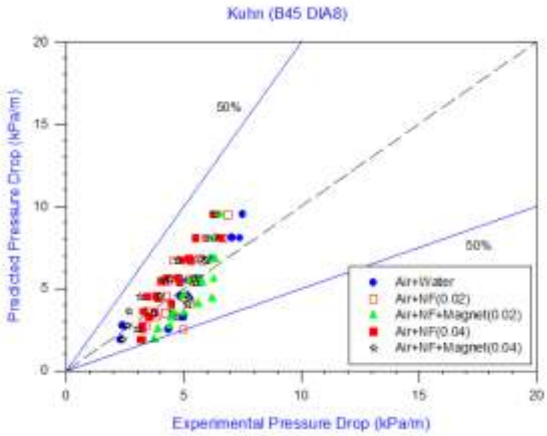
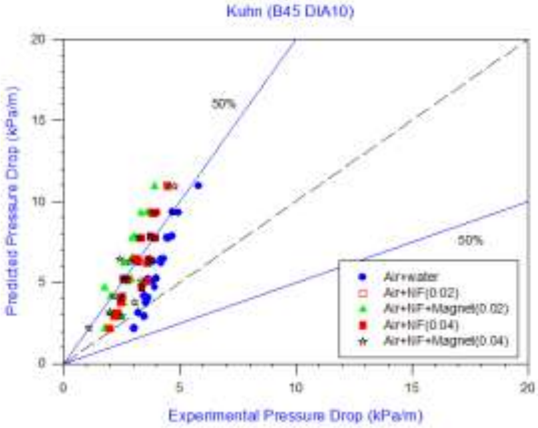


Fig.4 Comparison of various existing correlations with experimental data

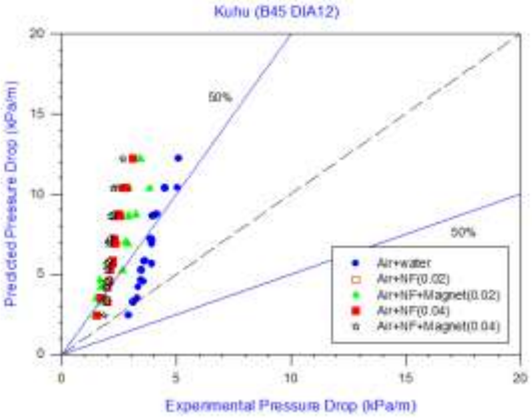
a)


Kuhn (B45 DIA8)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
Air+Water
Air+NF(0.02)
Air+NF+Magnet(0.02)
Air+NF(0.04)
Air+NF+Magnet(0.04)

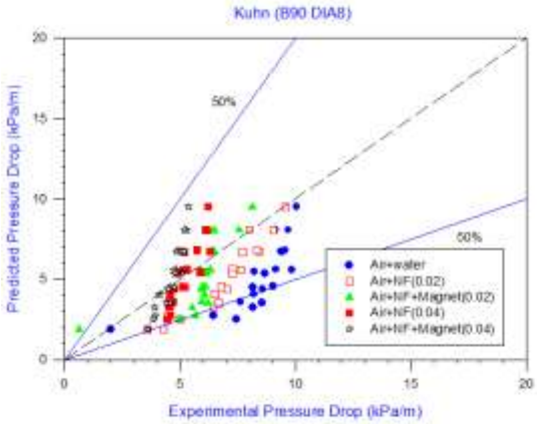
b)


Kuhn (B45 DIA10)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
Air+water
Air+NF(0.02)
Air+NF+Magnet(0.02)
Air+NF(0.04)
Air+NF+Magnet(0.04)

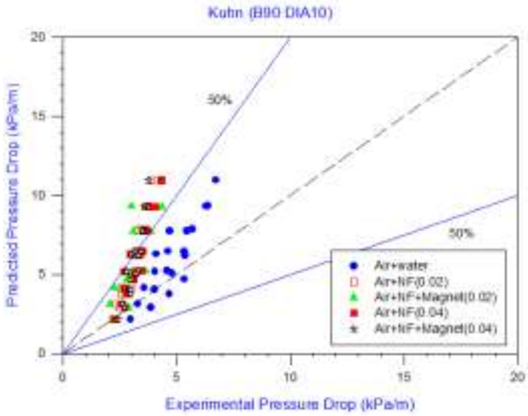
c)


Kuhu (B45 DIA12)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
Air+water
Air+NF(0.02)
Air+NF+Magnet(0.02)
Air+NF(0.04)
Air+NF+Magnet(0.04)

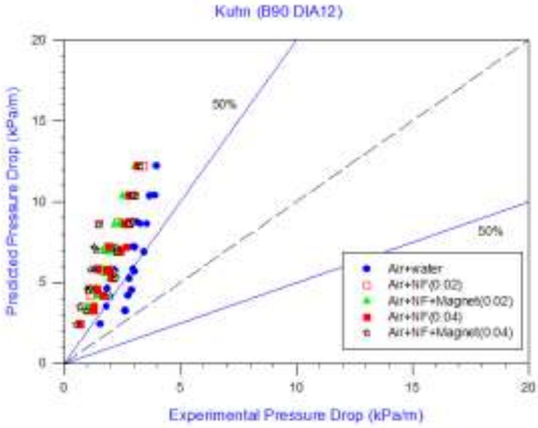
d)


Kuhn (B90 DIA8)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
Air+water
Air+NF(0.02)
Air+NF+Magnet(0.02)
Air+NF(0.04)
Air+NF+Magnet(0.04)

e)


Kuhn (B90 DIA10)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
Air+water
Air+NF(0.02)
Air+NF+Magnet(0.02)
Air+NF(0.04)
Air+NF+Magnet(0.04)

f)


Kuhn (B90 DIA12)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
5
10
15
20
50%
50%
Air+water
Air+NF(0.02)
Air+NF+Magnet(0.02)
Air+NF(0.04)
Air+NF+Magnet(0.04)

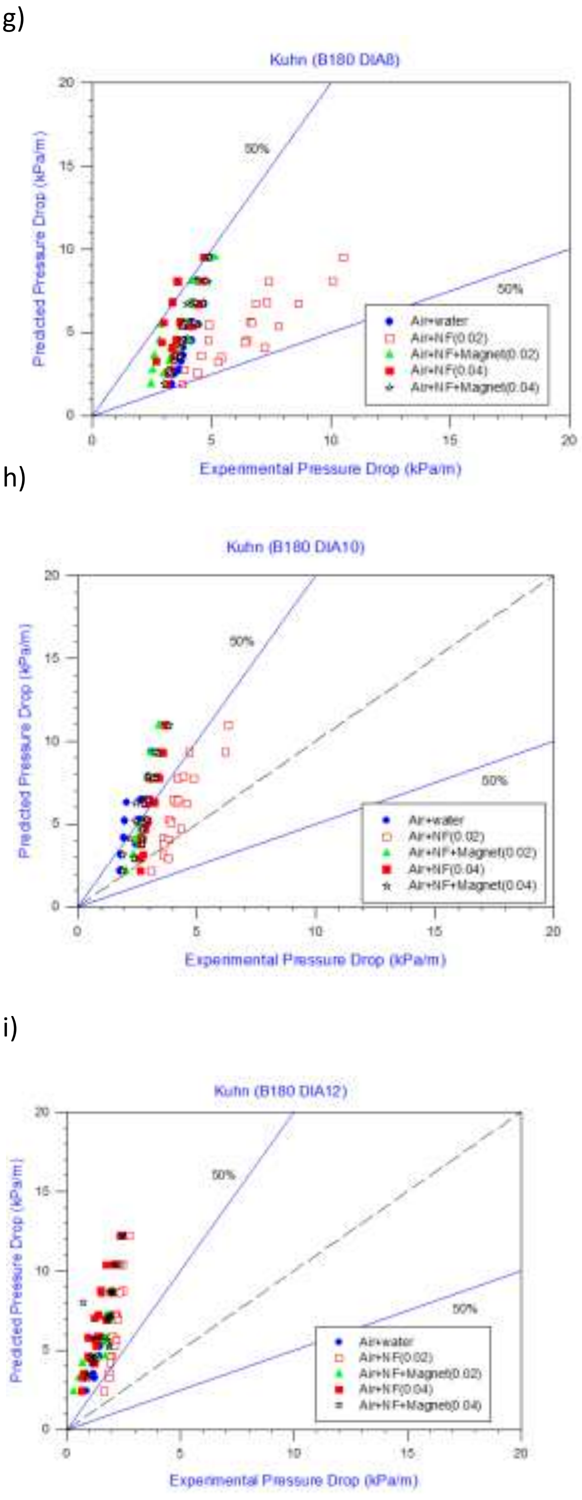
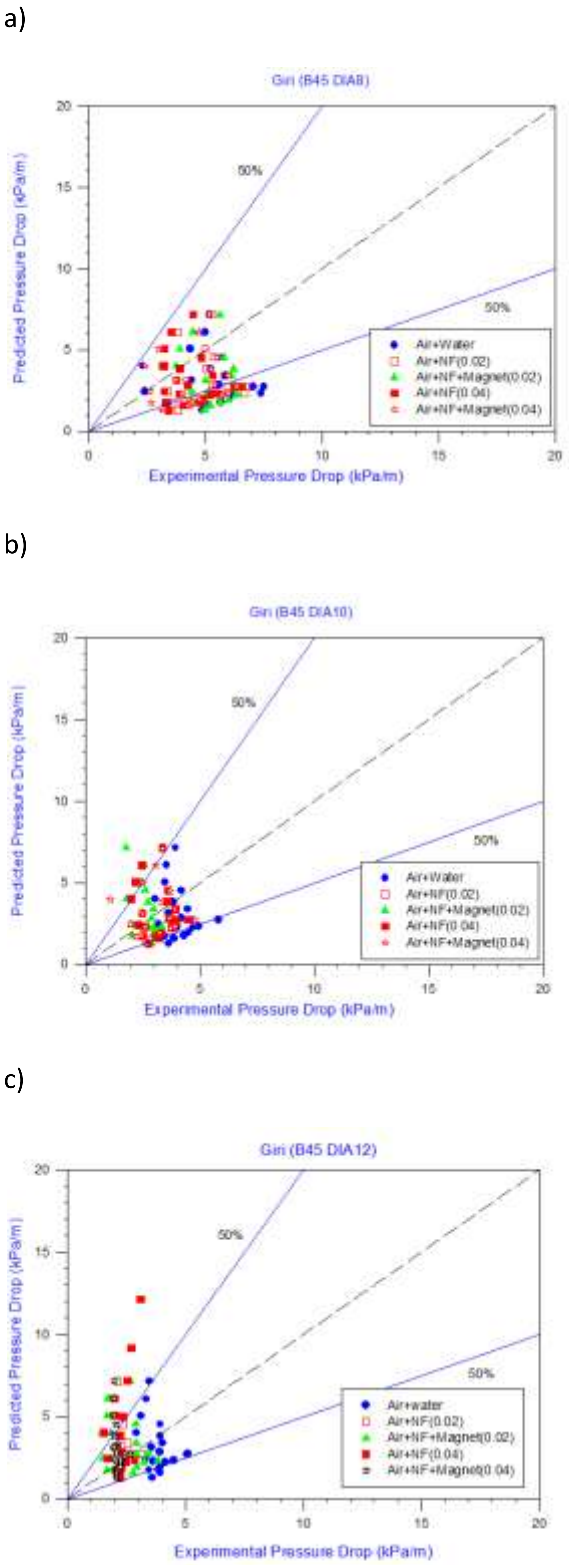
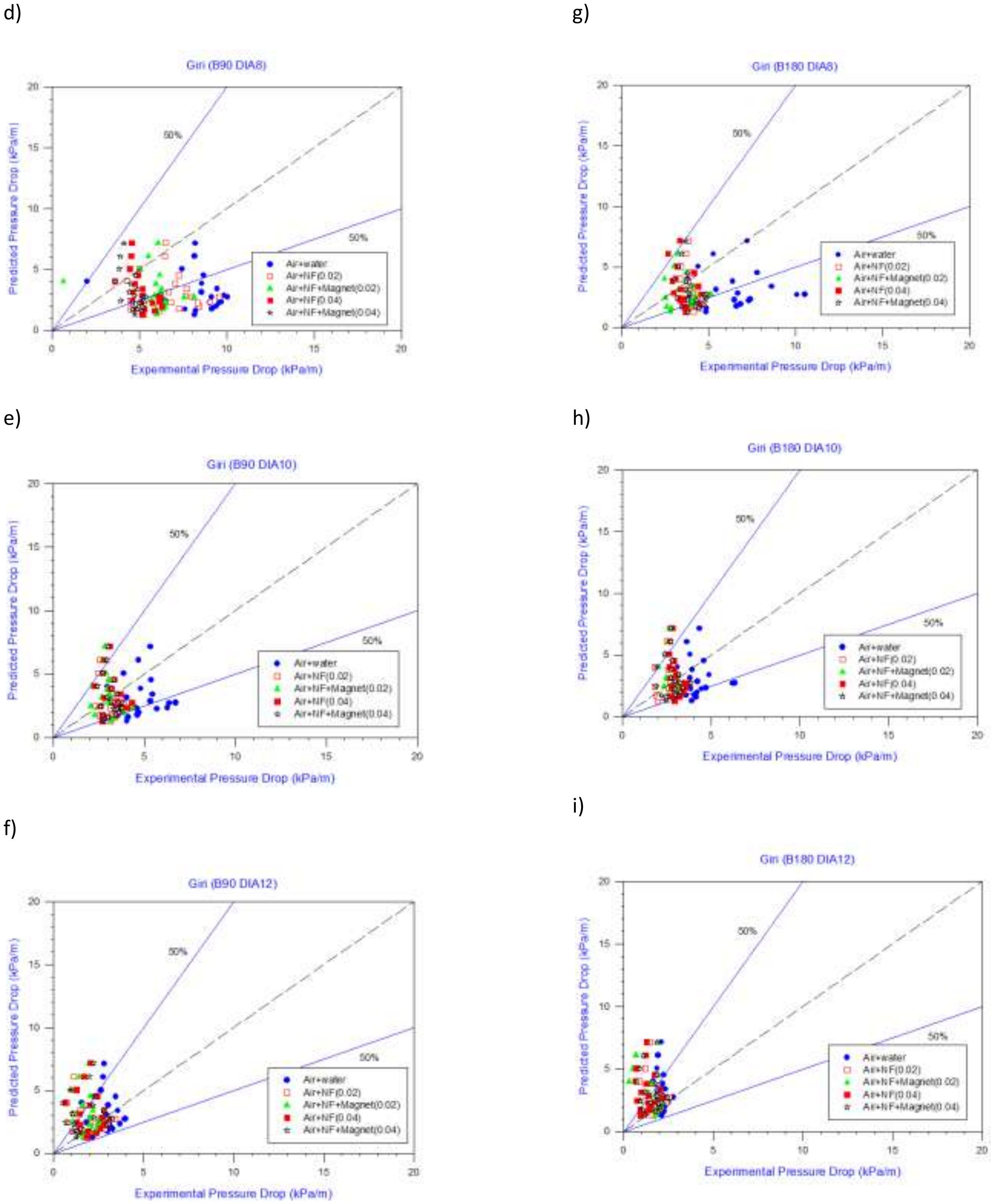


Fig.5 Comparison of Kuhn correlations with experimental data.





d)

e)

f)

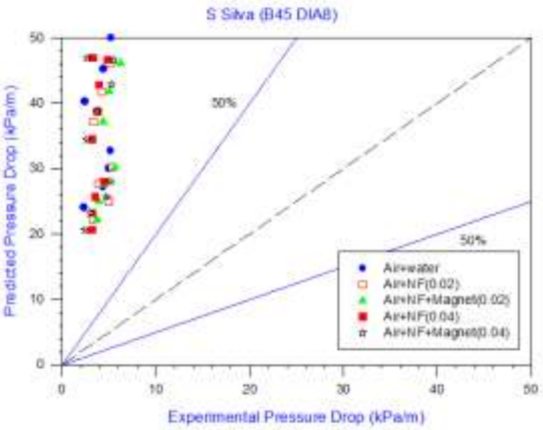
g)

h)

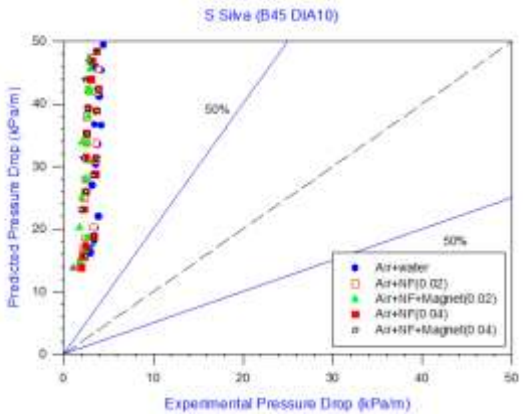
i)

Fig. 6 Comparison of Giri correlations with experimental data

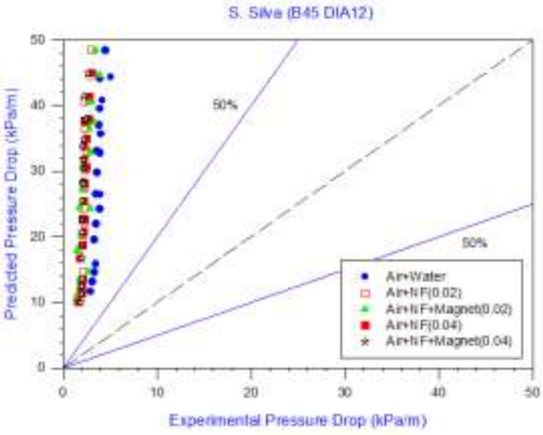
a)


S Silva (B45 DIA8)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
10
20
30
40
50
50%
50%
● Air+water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
☆ Air+NF+Magnet(0.04)

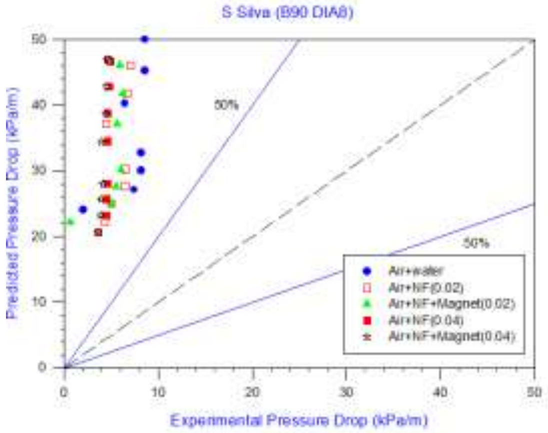
b)


S Silva (B45 DIA10)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
10
20
30
40
50
50%
50%
● Air+water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
☆ Air+NF+Magnet(0.04)

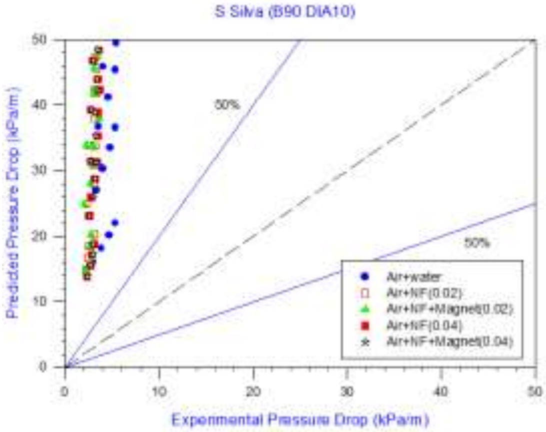
c)


S. Silva (B45 DIA12)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
10
20
30
40
50
50%
50%
● Air+Water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
★ Air+NF+Magnet(0.04)

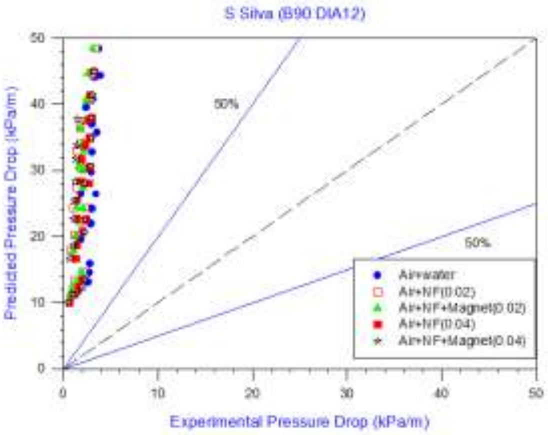
d)

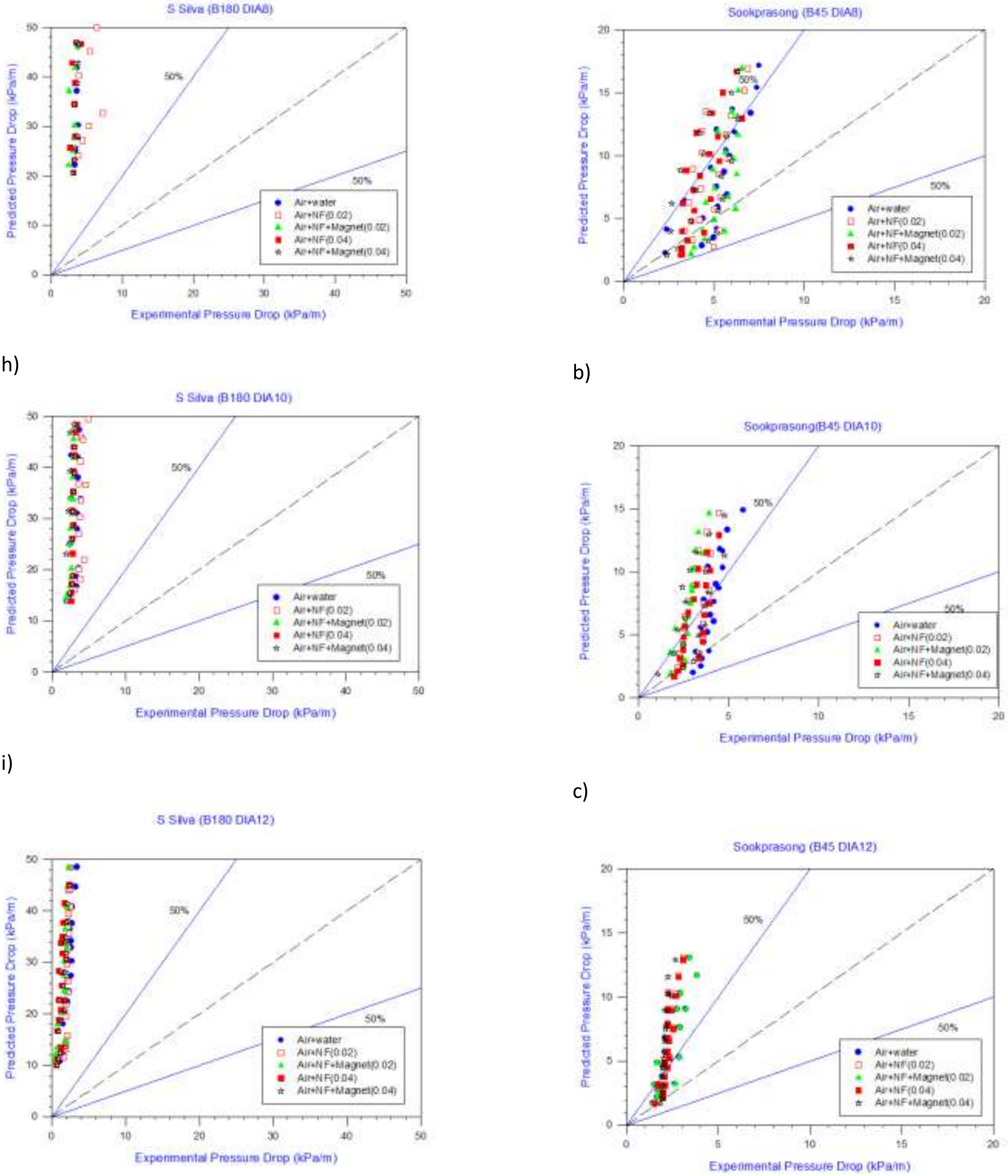

S Silva (B90 DIA8)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
10
20
30
40
50
50%
50%
● Air+water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
★ Air+NF+Magnet(0.04)

e)


S Silva (B90 DIA10)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
10
20
30
40
50
50%
50%
● Air+water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
★ Air+NF+Magnet(0.04)

f)


S Silva (B90 DIA12)
Predicted Pressure Drop (kPa/m)
Experimental Pressure Drop (kPa/m)
0
10
20
30
40
50
50%
50%
● Air+water
□ Air+NF(0.02)
▲ Air+NF+Magnet(0.02)
■ Air+NF(0.04)
★ Air+NF+Magnet(0.04)



g)

h)

i)

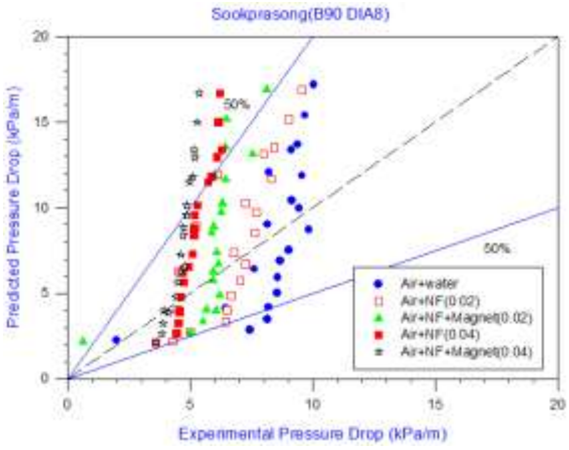
a)

b)

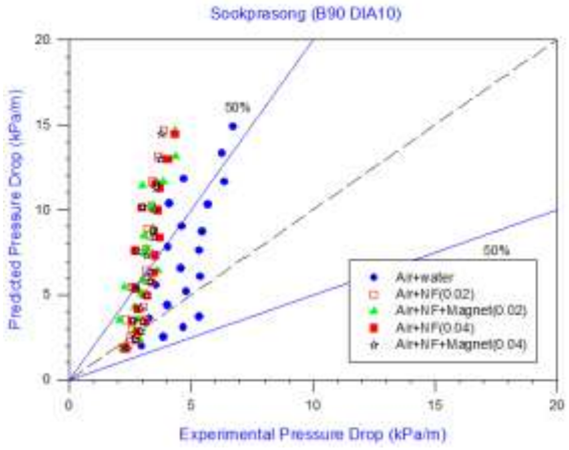
c)

d)

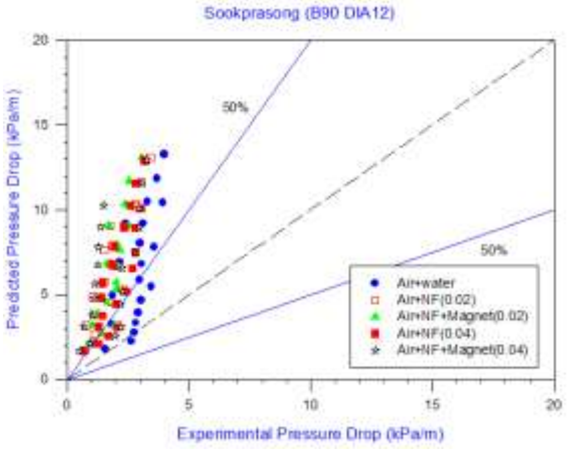
Fig. 7 Comparison of S Silva correlations with experimental data.



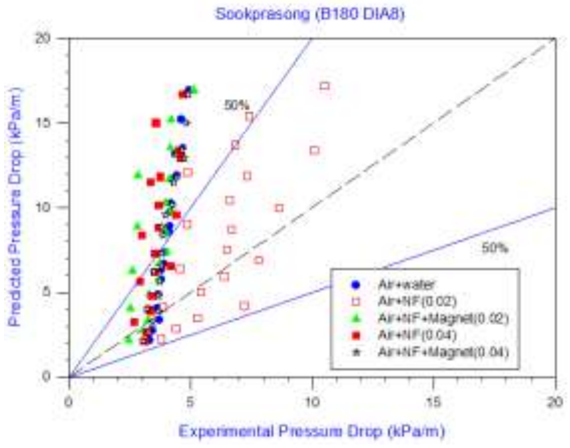
e)



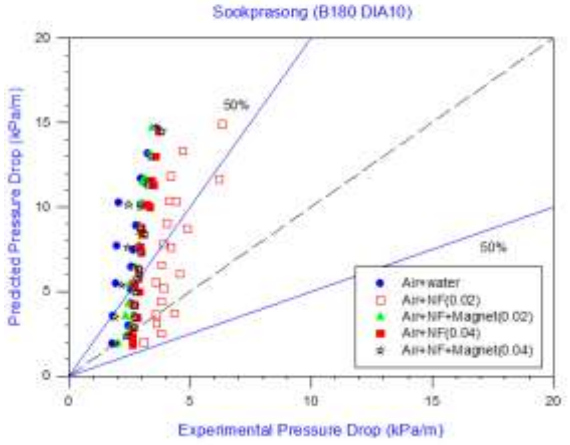
f)



g)



h)



i)

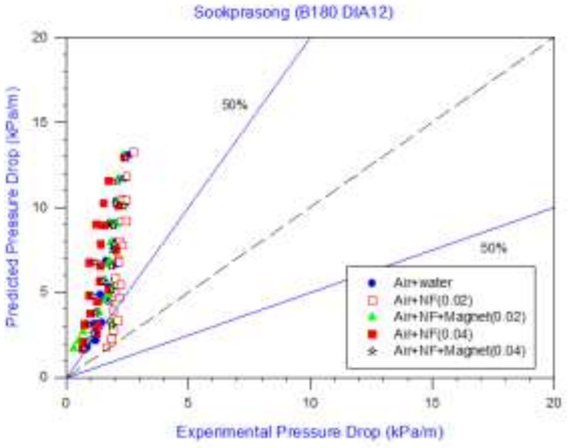


Fig 8 Comparison of Sookprasong correlations with experimental data.

V. CONCLUSIONS

The effect of constant water two-phase flow gives adequate results on the pressure drop of air-water flow in bend tubes with different ID and bend angle are investigated both experimentally and numerically. There are 6 numbers of existing correlations studied and compared with experimental data points. Also predicted results for nanofluid (Fe_3O_4) as two-phase frictional pressure drop and compared the result with the presence of a constant magnetic field.

1. Single phase water flow tests were performed for experimental validation and results confirmed the suitability of the test facility which can be used for two-phase flow investigation.
2. The frictional pressure drop enhanced with increasing flow rate and with decreasing internal diameter of tube.
3. Nanofluid used at different concentration results in slightly decreasing the pressure drop as compared to water but it also increases with increase in the concentration of the fluid. The constant magnetic field supplied through nanofluid also results in the increasing frictional pressure drop.
4. The prediction from Giri et al.(2016) model for all friction data points sets fall within the ±50% of error band. Giri et al.(2016) model concludes that the mean percentage of error is less than 55%.

VI. REFERENCES

[1] Autee A.T (2014). Experimental investigation of pressure drop adiabatic air-water two-phase flow in small diameter tubes and bend, Ph. D Thesis.
[2] Autee A.T, Srinivasa Rao S., Ravikumar Puli (2012). Experimental Study on Two-Phase Pressure Drop of Air-Water in small Diameter Tubes at Horizontal Orientation, Thermal Science, Online-First Issue.
[3] Autee A.T and Giri S.V (2016). Experimental study on two-phase flow pressure come by small diameter bends, Preservatives in Science, 8, pp. 621—625.
[4] Chisholm D. (1983). Two-phase flow in pipeline and heat exchangers, George Godwin, London, pp. 154-166.
[5] Chisholm D. (1880). Two-Phase flow in the bend. Int J Multiphase Flow; 6:363-67.
[6] Chisholm D, (1972). Pressure gradients due to friction during the flow of evaporating tow-phase mixtures in smooth tubes and channels, International Journal Heat Mass Transfer, Vol.16, pp.347-358.
[7] Domanski P .A, Hermes C J L (2006). An improved two-phase pressure drop correlation for 180 return bend. 3rd Asian Conf., Refrigeration and air conditioning, Gyeongju, Korea, May 21-23
[8] Friedel, L. (1979). Improved friction pressure drop correlations for horizontal and vertical two-phase flow, European two-phase flow Group meeting, Ispra.
[9] Giri S. V. (2016). Experimental Analysis of Adiabatic Adiabatic Air-Water Two-Phase Flow Pressure Drop in small Diameter Bends, M.E. Thesis.
[10] Hamad F.A., Faraji F. C., Santim G.S. (2016) Investigation of pressure drops in horizontal pipes with totally different diameters, International Journal of Multiphase Flow, pp. 120–129.
[11] Ito H., (1987). Flow in curved pipes. JSME Int. J., 30 543-552.
[12] Lockhart R W and Martinelli R C., (1949). Proposed correlation of data for isothermal two-phase two-component flow in pipes, Chem Engg Progress; 45:39-45.
[13] Padilla M, Revellin R, Bonjour J (2009). Prediction and simulation of two-phase pressure drop in return bend, Int J. of Refrigeration, 32, pp. 1776-1783
[14] Paliwad, A., (1992). Generalised method of pressure drop calculation across pipe component containing a two-phase flow of refrigerant, Int. J.
[15] Padilla M., Revellin R., Bonjour J. (2009) Prediction and simulation of two-phase pressure drop in return bends, Int. J. of Refrigeration, 32, pp.1776-1783.
[16] Rana K.B., Rajvanshi A.K., and Agrawal G.D. (2010). A visualization study of flow boiling heat transfer with nanofluid, Journal of heat and fluid flow, 2010, 13, 599-605.
[17] Silva S.L. , Resendiz, J. C (2010). Carvajal Mariscal, Tolentino Eslava, Pressure Drop Model Evaluation for Two-Phase Flow in 90 Degree Horizontal Elbows, Ingenieria Mecanica Tecnologia Y Dersarrollo Vol.3 No.4, 115-122.
[18] Sookprasong, P. (1980). Two-phase flow in piping components , Ph.D. Thesis University of Tulsa.
[19] Spedding P.L., Benard E. (1982). Gas-liquid two-phase flow through a vertical 90^0 elbow bend, School of Aeronautical Engineering, Queen's University Belfast, BT9 5AH, UK.
[20] Muller-steinhagen, H. And Heck, K, (1986). A simple pressure drop correlation for two-phase in pipes, chem. Eng. Process,20 pp.297-308.
[21] Toksha B.G. , Shirsath S.E., Patange S.M., (2008). Structural investigations and magnetic properties of cobalt ferrite solution nanoparticles ready by sol–

gel auto combustion methodology, Solid State Communications, 147 (11-12), 479-483.

[22] Venkatesan M., Sarit K. Das, A.R. Balakrishnan (2011). Effect of diameter on two phase pressure drop in narrow tubes, Experimental Thermal and Fluid Science, pp. 531 -541.